

# The Supernova Early Warning System

K.Scholberg<sup>1,\*</sup>

Duke University Physics Dept., Box 90305, Durham, NC, USA

Received 2007 Aug 24, accepted 2007 Dec 11

Published online 2008 Feb 25

**Key words** Core collapse, neutrinos, galactic supernovae

A core collapse in the Milky Way will produce an enormous burst of neutrinos in detectors world-wide. Such a burst has the potential to provide an early warning of a supernova's appearance. I will describe the nature of the signal, the sensitivity of current detectors, and SNEWS, the SuperNova Early Warning System, a network designed to alert astronomers as soon as possible after the detected neutrino signal.

© 2008 WILEY-VCH Verlag GmbH & Co. KGaA, Weinheim

## 1 The supernova neutrino signal

When a massive star reaches the end of its life, its core collapses. More than 99% of the binding energy of the resulting neutron star is released in the form of neutrinos and antineutrinos of all flavors, with energies in the tens of MeV range: the energy leaves via neutrinos because neutrinos interact so weakly that they readily leave the star. The neutrinos themselves bring information from deep inside the core; the detection of such a signal will yield great insights into neutrino properties and core collapse physics (*e.g.* Raffelt 2007). Of particular interest for this workshop is that the timescale of neutrino emission is a few tens of seconds, promptly after core collapse; the photon signal, in contrast, can take hours or even days to emerge from the stellar envelope. Thus, the detection of a burst of neutrinos will give astronomers an early warning of a nearby supernova.

So far there has been only one observed instance of core collapse neutrino emission: for SN1987A in the LMC, two water Cherenkov detectors, IMB and Kamiokande II, observed a total of 19 neutrino interactions between them (Hirata et al. 1987; Bionta et al. 1987). Two scintillator detector observations were also reported (Alekseev et al. 1987; Aglietta et al. 1987). The water Cherenkov neutrinos were recorded 2.5 hours before the first light was observed from the supernova; however the neutrino signal was only retrieved from data tapes after the fact. Next time we will do better. An early observation of the supernova light curve turn-on will bring information about the progenitor and its environment, which can in turn feed back to neutrino physics. The aim of SNEWS is to provide the astronomical community with an early warning of a supernova's occurrence, as well as to improve global sensitivity to a supernova neutrino burst via inter-experiment collaboration.

## 2 Neutrino detectors

Because neutrinos interact so weakly, in spite of their huge flux, enormous detectors are required to see a substantial signal. Typically about a kiloton of target material is required to observe a few hundred interactions. This limits the distance sensitivity of terrestrial neutrino detectors to the Milky Way neighborhood: the largest neutrino detectors of the current generation have a range of a few hundred kpc. The typical distance to the next nearby supernova will be 10–15 kpc (Mirizzi, Raffelt & Serpico 2006). The next generation of megaton-mass-scale detectors may reach Mpc distance sensitivity, extending reach to Andromeda and other Local Group galaxies.

We can expect a Milky Way core collapse about every 30 years. Perhaps one in six supernovae will stand out obviously, and some may never become optically bright. However, with current technology spanning an enormous range of electromagnetic wavelengths, and including gravitational wave sensitivity, even supernovae that fizzle may be detectable in some channel.

A number of neutrino detectors are in existence world-wide. Typically, detectors must be underground for cosmic ray shielding. Most existing supernova neutrino detectors exploit the inverse beta decay interaction of electron antineutrinos on free protons,  $\bar{\nu}_e + p \rightarrow n + e^+$ , where the energy loss of the positron is detected, sometimes followed by neutron-capture gammas. The rate of this reaction is relatively large compared to other neutrino interactions in this energy regime. Furthermore, detectors with large numbers of free protons, such as those made of hydrocarbon or water, can be constructed cheaply. Note that predominance of inverse beta decay as the main detection channel means that primary sensitivity is to electron antineutrinos, which are only one component of the flux.

The main supernova neutrino detector types are:

- **Scintillation detectors**: such detectors consist of large volumes of hydrocarbon,  $C_nH_{2n}$ . Organic scintillating

\* Corresponding author: e-mail: schol@phy.duke.edu

materials produce light when charged particles lose energy in them, and the resulting photons are picked up by photomultiplier tubes. Scintillation light is isotropically emitted, so directional detection is not generally possible even for asymmetric processes. Examples of currently running scintillation detectors are LVD and Borexino in Italy, KamLAND in Japan, and Baksan in Russia.

- **Water Cherenkov detectors:** these employ ultrapure water. Neutrino-induced charged particles move faster than the speed of light in water and produce Cherenkov radiation; as for scintillation detectors, the Cherenkov photons are picked up by photomultipliers. Although most interactions in a water detector are inverse beta decay processes, a small fraction will be elastic scattering of neutrinos from atomic electrons,  $\nu + e^- \rightarrow \nu + e^-$ . This process is of particular interest because the electrons are kicked in the direction the neutrinos are traveling; because Cherenkov radiation is directional, these scattering interactions offer a means of knowing the direction of the supernova (see section 3). Super-Kamiokande in Japan is currently the only instance of a large water Cherenkov detector; with a 50 kiloton mass, it is currently the most sensitive of the world's supernova neutrino detectors.
- **Long string water Cherenkov detectors:** although detectors built of long strings of photomultiplier tubes embedded in water or ice are primarily designed for high energy ( $> \text{GeV}$ ) neutrinos, some are capable of observing diffuse photons from inverse beta decays in ice or water as a coincident increase of count rates in many photomultipliers (Halzen, Jacobsen & Zas 1995). AMANDA/IceCube at the South Pole has Galactic sensitivity.
- **Other supernova neutrino detectors:** other target materials can be used for supernova neutrino detection, and a number of novel detectors are proposed or under construction. Liquid argon has excellent potential for  $\nu_e$  tagging, and proposed detectors based on lead or iron will have good sensitivity to neutrino flavors other than  $\bar{\nu}_e$ . See Scholberg (2007) for a review of current and future supernova neutrino detection.

### 3 Considerations for the early warning

What we want from an early warning can be summarized as “The 3 P”s:

- **“Prompt”:** time is of the essence for a supernova early warning; we are essentially racing the shock wave. A key factor in a prompt warning is the requirement of a coincidence between detectors, since it allows an automated alert. Any individual detector's signal requires human checking, which can slow things down. Automated coincidence alerts on a timescale of minutes have been demonstrated.

- **“Pointing”:** obviously, the better one can point to the location of the supernova, the more likely it is that the supernova will be found promptly. Unfortunately, pointing in neutrinos (Beacom & Vogel 1998) is difficult: the best bet will be to make use of neutrino-electron elastic scattering interactions,  $\nu + e^- \rightarrow \nu + e^-$ , for which the kicked electron points away from the source. This is a few percent of the total signal. Super-K's pointing will be a few degrees for a Galactic center event. No other existing detectors have directional capability. Triangulation using timing of signals at different detectors around the globe is in principle possible, but is in practice too difficult with expected statistics. Millisecond precision is needed, and we expect  $10^3 - 10^4$  interactions spread out over tens of seconds.
- **“Positive”:** here the criterion is to have very few false alerts (see also section 5): we aim for fewer than one accidental coincidence per century. The coincidence requirement is essential here. We require, for a 2 out of 3 coincidence, that each individual experiment's false alarm rate does not exceed about one per week.

### 4 SNEWS implementation and status

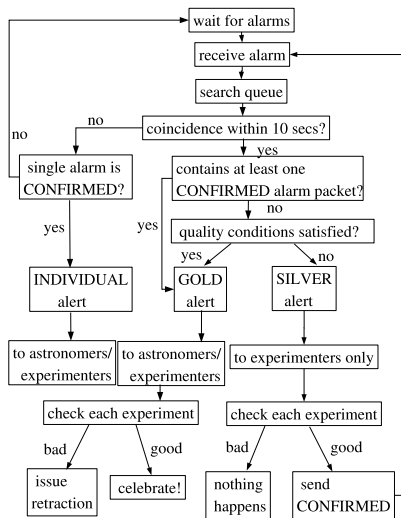
SNEWS, the Supernova Early Warning System (Antonioli et al. 2004), aims to address all of the above criteria. The implementation is relatively simple. Each individual neutrino experiment implements its own neutrino burst monitoring system, tailored to the features of that experiment, with interesting burst criteria defined by each experimental collaboration. A “client” at each experiment sends out an alert datagram if a sufficiently interesting burst of neutrino interaction candidates is found. A “coincidence server” waits for datagrams from each experiment's clients. If the server finds a coincidence within 10 seconds, then it sends out an alert to the SNEWS alert mailing list. Astronomers can sign up for the SNEWS alert mailing list at [snews.bnl.gov](mailto:snews.bnl.gov). SNEWS has been running in automated mode since 2004 (and in a non-automated mode since 1999).

We classify alerts as “gold” and “silver”: gold alerts go directly to the astronomical community, whereas silver ones go to experimenters only. A gold alert requires that a number of quality checks be satisfied, and also that experiments involved in the coincidence do not have a recent history of sending alarms at an higher than usual rate. Silver alerts may be upgraded after human checking.

Individual experiments may also use the SNEWS alert infrastructure for human-checked (hence slower) confirmed alerts. Figure 1 shows our current flowchart, updated since Antonioli (2004) was published.

Our main coincidence server runs at Brookhaven National Lab and a backup server is also kept running at the U. of Bologna. The datagram protocol is SSL-encrypted TCP/IP, and server's alert output is PGP-signed email.

The experiments currently participating in SNEWS are Super-Kamiokande in Japan (Ikeda et al. 2007), LVD (Agli-



**Fig. 1** Flowchart summarizing the sequence of events and decisions that determine whether an alert is GOLD, SILVER (or INDIVIDUAL).

etta et al. 1992) in Italy, and IceCube/AMANDA (Ahrens et al.) at the South Pole. The Sudbury Neutrino Observatory in Canada (Virtue 2001) participated until it completed its running phase in 2006. We expect future experiments to join as they come online.

Amateur astronomers are an integral part of SNEWS. They have wide area viewing capability, enthusiasm and expertise. In the absence of precise neutrino-derived pointing information, amateurs may be the first to pinpoint the supernova location. *Sky and Telescope* magazine provides an AstroAlert mailing list to reach amateur astronomers and serves as a clearinghouse for amateur responses: ([www.skyandtelescope.com/resources/proamcollab/AstroAlert.html](http://www.skyandtelescope.com/resources/proamcollab/AstroAlert.html)). A successful amateur test was performed in February 2003, for which a known fake target (the asteroid Vesta) was selected and a tagged fake alert sent via the AstroAlert list. This demonstrated timely and accurate response from amateurs worldwide.

It should be technically straightforward to expand the SNEWS alert output to communicate with robotic telescope networks. Although pointing information may be poor or unavailable, telescopes with wide fields of view may be able to respond appropriately. We plan to implement VOEvent protocol alert output in the near future.

## 5 Discussion

We are often asked by astronomers why SNEWS does not turn thresholds down so as to get a higher rate of false alerts; this would improve sensitivity, exercise the system, and keep interest high.<sup>1</sup> The answer is primarily sociological. In the

<sup>1</sup> We have in fact performed a high rate test, as reported in Antonioli et al. (2004). However we require very low false alert rate for output to the wider community.

community represented at this workshop, there is high tolerance for “junk” alerts; astronomers are awash in data and the main problem is to sift the interesting information from the copious noise. However, in the neutrino community, because true events are so rare, there is strong inhibition against issuing any kind of false alerts. Furthermore, decrease in threshold yields only modest increase in sensitivity—most detectors are already sensitive to the entire Galaxy and moderate improvement does not bring many new candidate stars into range. Since the dearth of data makes it all the more urgent to gather any information one can when the supernova actually does happen, the SNEWS network’s problem becomes one of maintaining readiness during decades-long data-less deserts. Well-tagged, well-advertised fake alerts are one way of maintaining interest and ability to react.

## 6 Summary

In summary, the key points of relevance for astronomers interested in transients are as follows:

- The neutrino signal for a core collapse event precedes its electromagnetic fireworks by hours, or perhaps tens of hours.
- The burst of neutrinos itself lasts tens of seconds.
- The pointing from the neutrinos will be a few degrees in an optimistic case. There may be no pointing information at all, or the pointing information may be not be available immediately.
- Currently running experiments are sensitive to a core collapse in the Milky Way, or just beyond. The next generation of detectors may reach to Mpc range.
- A few Galactic supernovae are expected per century.
- SNEWS is online, and can provide an alert within minutes of a Galactic core collapse. Anyone may sign up for the automated SNEWS mailing list. We hope to expand the alert soon to VOEvent-based networks.

**Acknowledgements.** The author acknowledges the contributions of the inter-experiment SNEWS working group. SNEWS is supported by the U. S. National Science Foundation.

## References

- Aglietta, M. et al.: 1987, *Europhys Lett.* 3, 1315
- Aglietta, M. et al.: 1992, *Nuovo Cim. A* 105, 1793
- Ahrens et al.: 2002, *Astropart. Phys.* 16, 345
- Alekseev, E. N. et al.: 1987, *JETP Lett.* 45, 589
- Antonioli, P. et al.: 2004, *New J. Phys.* 6, 114
- Beacom, J. and Vogel, P.: 1999, *Phys. Rev. D* 60, 033007
- Bionta, R. M. et al.: 1987, *Phys. Rev. Lett.* 58, 1494
- Halzen, F., Jacobsen, J.E. and Zas, E.: 1996, *Phys. Rev. D* 53, 7359
- Hirata, K. et al.: 1987, *Phys. Rev. Lett.* 58, 1490
- Ikeda M. et al.: 2007, *arXiv:0706.2283*
- Mirizzi, A., Raffelt, G.G. and Serpico, P. D.: 2006, *JCAP* 0605, 012
- Raffelt, G.: 2007, *arXiv:astro-ph/0701677*
- Scholberg, K., *arXiv:astro-ph/0701081*
- Virtue, C. J.: 2001, *Nucl. Phys. Proc. Suppl.* 100, 326